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# THE BASIS OF PRE-CAMBRIAN CORRELATION.[1]

## II

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That was indeed a fair and sunlit earth which our predecessors, the first geologists, had presented to them for study. The uniform strata of the newer periods of our earth's history in their succession, well exposed, and following one another in due and regular order, everywhere contained abundant fossil remains which afforded a certain clue by which correlation could be made even in widely separated areas. We, their unfortunate successors, in pursuing our studies are obliged to descend into the deeper parts of the earth where the light begins to fail and when once we pass through that last grim portal into the drear pre-Cambrian world, we enter into what these earlier geologists regarded as a hopeless chaos. Here we lose the guiding thread of life, and the darkness deepens. At first we could dimly descry but the outlines of the vast indeterminate ruins of former worlds, but as our eyes become accustomed to the darkness these become somewhat more distinct and we recognize succession even in this ruined waste.

It may be that being a petrographer I overestimate the value of paleontology, but, like other things, we prize it most highly when it is lost and we are obliged to look for something to take its place. The working-out of the stratigraphical succession by detailed mapping in special areas teaches us much, but unfortunately the areas showing such succession are usually limited and isolated and the criteria for correlating the successions in separated areas, and especially in widely separated areas, are as yet undiscovered.

The vice-president of our section, Dr. Bailey Willis, in inviting me to take part in this symposium, has suggested that I should treat this subject of pre-Cambrian correlation if possible on broad lines, and I therefore venture today to follow Faust's aspiration, "Schau' alle Wirkenskraft und Samen," and present a certain aspect of the subject which I hope may at least be suggestive of a line along which some advance may be made in the correlation of these ancient rocks.

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[1] Read before Section E of the American Association for the Advancement of Science, December, 1908.

In his *Research in China* (Vol. II, chap. viii) Dr. Bailey Willis has put forward a theory to account for the origin of continental structure. In each of our present continents there are areas which during the evolution of the continent have always tended to rise—these he calls *positive* elements. There are certain other areas which have always shown a tendency to sink, relatively to the adjacent masses—these he calls *negative* elements. The movement of these elements is due to the greater relative density of the negative elements causing them to sink, while the relatively lighter positive elements tend to rise so as to bring about an isostatic adjustment. There have been horizontal movements as well as those in a vertical direction. These are of notable magnitude and their effects are seen in the schistose structure of these once deep-seated rocks and the overthrust and folded structures of the more superficial strata. The tendency toward vertical displacement has actually resulted in movement only at long intervals and during relatively short periods. Hence we may recognize cycles of diastrophism each one of which comprises (a) a comparatively brief period of orogenic and epeirogenic activity which results in elevated lands and restricted mediterranea; and (b) a comparatively long period of continental stability, which results in extensive peneplanation. The critical times which bring out continental structure are the epochs of diastrophic activity. During periods of inactivity the distinction between the positive and negative elements becomes less obvious and may even become obscured by extended peneplanation and marine transgression.

In a subsequent paper,[1] the same writer outlines the positive and negative elements of the continent of North America. The Canadian Shield, which is also called *Laurentia*, is at once the largest and the most readily distinguished positive element of the continent. It has an area of approximately two million square miles and the true boundary may be traced along the St. Lawrence Valley into the deep of Baffin's Bay and then north of the Arctic Archipelago (which is scarcely to be separated from Greenland) across the Arctic Ocean and back to the mouth of the Mackenzie. Beneath the Cretaceous of western Canada, the margin of this element lies hidden. It ranges past Lake Winnipeg toward the state of Wisconsin, and then follows the shore of the Paleozoic mediterranean east to the Adirondacks and St. Lawrence.

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[1] Bailey Willis, "A Theory of Continental Structure Applied to North America," *Bull. Geol. Soc. of America*, Vol. XVIII, p. 392.

Now it would seem, if we select a single positive element such as Laurentia—remembering that the critical diastrophic periods will be short and the intervening periods of deposition and accumulation will be of long duration—that these epochs of diastrophism, with their development of schistose structure in the moving masses and the associated phenomena of igneous intrusion, might be employed as a basis for the subdivision of Proterozoic time, and if the element moved as a whole, might even serve as a basis of correlation over the whole vast area. Laurentia, however, has not as yet been studied geologically except in a general way. Its detailed study will supply problems for generations of geologists yet unborn. Its southern margin alone, and that only in a few comparatively small areas, has been mapped in detail, but nevertheless exploratory and reconnaissance work has been carried out over almost the whole of the great expanse of this ancient continent chiefly by the officers of the Geological Survey of Canada, so that we have a good general knowledge of the main outlines, at least, of its geological history. It is proposed here to present a general statement of the results obtained, as they bear upon the history of Laurentia in pre-Cambrian times and afford a basis for pre-Cambrian correlation, making use of this principle of critical diastrophic epochs and drawing evidence from the area as a whole, rather than from a few restricted areas on its southern border.

This task is rendered comparatively easy owing to the fact that a critical digest of the mass of information concerning the pre-Cambrian rocks of the great central and northern portions of Laurentia, which is found disseminated through the reports and papers by the various geologists who have worked in this great area, has recently been prepared by Dr. George A. Young, of the Geological Survey of Canada, who has himself traveled very extensively in this northern country. I am indebted to Dr. Young for permission to make use of this unpublished material, but the original papers have been consulted in the case of all the more important occurrences.

The great expanse of Laurentia is underlain predominantly by the rocks of the Laurentian system. These consist of gneisses in infinite variety which in the majority of cases have the mineralogical composition of granite, although some present foliated varieties of rocks ranging from syenite to diorite. The foliation is in some cases so faint that it can be detected only on large weathered surfaces, but generally it is quite distinct or even striking. In addition to the foliation the rock often displays a very distinct banding due to the alternation of varieties of diverse character or composition. This foliation is in many, and possibly in the majority of cases, a primary structure and the darker bands very frequently represent included masses of overlying rocks, softened and in some instances partially digested. This foliation and banding was at one time regarded as a partially obliterated bedding and considered to present indisputable evidence that the rocks were of sedimentary origin. These gneissic rocks are not all of the same age, for frequently one mass can be seen to cut another. In addition to these gneissic granites, syenites, and diorites, however, the Laurentian comprises other kinds of plutonic rocks of very diverse character. Thus, from Minnesota to the shores of Ungava Bay, intrusions of anorthosite are found. Several of these, for the most part distributed along the margin of the protaxis in the province of Quebec and in the Ungava peninsula, present areas of from a few miles to 10,000 square miles in extent, and represent some of the more recent pre-Cambrian plutonics, although they themselves have been cut by still later granites. In fact, it is becoming more and more evident with the progress of geological investigation that the Laurentian is a vast complex of plutonic rocks of widely varying types and differing greatly in age, although there is no evidence to show that any of them were intruded later than the close of the Proterozoic. Whether in this enormously extended complex, which we term the Laurentian in the northern protaxis, there still survive any primitive sediments or any portion of an original crust, through which these great bodies of intrusive rocks forced themselves, is unknown. None have as yet been distinguished with certainty, but if any do exist they are probably similar in composition to these earliest intrusive rocks and might easily escape notice.

It is certain, however, that the overlying Keewatin and Grenville series were deposited on some floor, although this floor has remained undiscovered up to the present time. Either the Laurentian gneiss, or some part of it, represents the original floor, subsequently melted and intruded into the overlying sediments, or the original floor remains unrecognized among the enormous bodies of intrusive rocks which resemble it in character.

Resting on this Laurentian complex, in the region of the Great Lakes, although penetrated by it, the lowest sedimentary series here recognized is the Keewatin series, a great body of rocks largely of pyroclastic origin, but in some districts containing great thicknesses of epiclastic material.

It is not necessary here to make further reference to this great series which has been so well described by so many writers. In this region it is the oldest sedimentary rock recognizable as such.

In the region of the St. Lawrence Valley this Keewatin is not seen, but there is a series of extraordinary thickness and enormous areal extent composed essentially of limestones, which rocks are practically absent in the Keewatin. Whether this series, known as the Grenville series, is the equivalent of the Keewatin is unknown as yet. If it be, the designation of the Keewatin by Van Hise as a series composed essentially of pyroclastic material to which stratigraphic methods cannot be applied and the assumption that such material characterized the earliest stratified deposits of the earth's history, must be abandoned, for the Grenville series is distinctly stratified and is one of the greatest limestones series in the earth's crust. However that may be, these two series constitute the oldest sediments in the earth's crust recognizable as such in their respective districts. Similar rocks apparently characterize extensive areas in the more northern and remote portions of Laurentia representing the oldest recognizable sediments in these districts.

At the close of this first period of long-continued sedimentation there came an epoch of diastrophism—a thrust exerted from a southeasterly direction against the ancient continent threw these series into a succession of great folds running approximately parallel to the present valley of the St. Lawrence. Enormous bodies of granitic magma rose in great bathyliths along the axes of the folds, disintegrating, fraying out, metamorphosing and partially absorbing the lower surfaces of the invaded sediments. Everywhere over thousands of square miles these ancient sedimentary rocks can be seen to have floated on the granite magma or to have been sunk into it and to have been cut to pieces by apophyses of it. That these movements were, in many cases at least, very slow, is shown by the fact that a study of the primary gneissic structure displayed by the bathyliths demonstrates that the upward movement of the latter began before crystallization had set in and continued while the magma was slowly filling with the products of crystallization and until it finally froze into a solid rock. This epoch of diastrophism, resulting in the elevation of great tracts of country, brings to a close the first clearly recognizable chapter in the history of Laurentia.

After prolonged and profound denudation the sea again transgressed upon the continent of Laurentia and in this sea were laid down the strata of the earlier Huronian time. The sea at this time passed over what is now the region of the Great Lakes and extended at least as far north as Lake Mistassini and as far west of the head of Lake Winnipeg. Locally it evidently extended as far inland as the latitude of the northern end of Hudson Bay. Within this earlier Huronian time there was, following the deposition of the Lower Huronian, a period of subordinate elevation and depression in the district of the Great Lakes marked by the deposition of the Middle Huronian. At the close of this period of deposition, there was again an epoch of widely extended diastrophism due to a thrust exerted upon the southern portion of the continent from the ocean bed to the southeast and resulting in the widespread folding of the sediments which had been deposited over the southern portion of the protaxis, into a series of mountain ranges running in a northeasterly to southwesterly direction, with accompanying metamorphism of the folded strata and deep-seated intrusion of vast amounts of igneous rock. It may be that the great body of sediments forming the Grenville series really belongs to this rather than to the earlier Keewatin period, but be that as it may, these great orogenic movements which took place at the close of the earlier (Lower and Middle) Huronian time, brought to a close the second great chapter in the pre-Cambrian history of Laurentia.

There then followed a period of deep and long-continued erosion, during which the Lower and Middle Huronian and the underlying sedimentaries were swept away over the greater part of the region, leaving only the lower portion of the folds—the roots of the mountains—in the form of long narrow belts, separated by the granitic rocks marking the axes of the intervening anticlinal uplifts. This period of profound erosion constitutes what Lawson has termed the Eparchean Interval. Up to this time the movements which affected the continent of Laurentia were due, as has been stated, to thrusts coming from the southeast and caused by the negative element underlying the Paleozoic plain in this direction, at that time constituting the ocean bed, by its subsidence crowding against the positive element which formed the continent of Laurentia. This is seen, as has been stated, in the distribution of the older rocks of the first two chapters of the pre-Cambrian in the form of long narrow belts running in a general northeasterly and southwesterly direction and representing the downward sagging portions of the ancient folds.

Succeeding this long period of intense and widespread erosion, which followed upon the conclusion of Middle Huronian or pre-Animikie time, there was again a very widespread transgression of the sea upon the surface of the continent of Laurentia. In this was laid down a series of sediments which while occurring at localities sometimes separated from one another by hundreds of miles, yet preserve the same general features. These younger rocks form chains of islands fringing the east coast of Hudson Bay over a distance of about three hundred miles and have been described under the title of the Nastapoka series. This assemblage of beds dips toward Hudson Bay, generally at low angles, and lies in long parallel ridges with steep eastern faces. The strata comprise a group of arkoses and sandstones overlain by sandstones, argillites, cherty limestones and dolomites and calcareous shales with great intrusive sheets of diabase. The series has been found in places to have a thickness of at least three thousand feet and is further characterized by the occurrence at certain horizons of beds of banded jaspilite and iron ores. In the interior of Labrador, where the series dips at low angles toward the Atlantic, there is throughout a zone at least three hundred miles long, a development of similar rocks and here again occur the jaspilite beds. On the Atlantic side, at the head of Hamilton inlet, and further up the river of the same name, occurs a similar series, while on the Atlantic shores, far north, is found a great group presenting many like features. West of James Bay and south of Hudson Bay, rocks lithologically like the Nastapoka series underlie a hilly district rising like an island above the surrounding flat-lying Paleozoic beds. In this great district of the pre-Cambrian west of Hudson Bay, large areas bordering the Arctic about the mouth of the Coppermine River, and extending to Great Bear Lake, are underlain by a development of rocks resembling in nearly all respects the Nastapoka series and similar rocks have been described from the region about Great Slave Lake.

In all these widely separated localities great developments of the same rocks occur and often are accompanied by beds of jaspilite and iron ore. Everywhere the members present the same general arrangement, the strata cut by many faults, dipping at comparatively low angles and forming ridges frequently capped by diabase, while in most cases the beds have been found overlying with a most striking unconformity older granitic and gneissic rocks. These points of similarity seem to indicate that the scattered groups are all of about the same age and belong to a pre-Cambrian series probably at one time nearly continuous over the northern regions from the shores of the north Atlantic to about the valley of the Mackenzie. In Labrador and in the districts west of Hudson Bay the evidence indicates that the Nastapoka series was deposited after an epoch of severe erosion. Lake Mistassini, in northern Quebec, lies in a basin-like depression occupied by nearly flat-lying beds of cherty dolomite representing a portion of the Nastapoka series, while south of the lake these rocks have been found almost in contact with a development of the Lower (or Middle) Huronian, differing in no essential features from this group of rocks as found in numerous localities further southwest toward Lake Superior. The Lower Huronian is in a highly disturbed condition and has been penetrated by large bodies of granite. Neither the disturbances nor the granitic intrusions have affected the near-lying Nastapoka series so that the latter seems to be undoubtedly of post-Lower (or Middle) Huronian age, to have been formed after the Lower Huronian had been folded and invaded by the granites and then deeply eroded. The relation of the two series resembles that existing between the Animikie and Lower Huronian at Port Arthur, and largely on these grounds the Animikie or Upper Huronian of the Lake Superior region and the Nastapoka series of Labrador and the territories south and west of Hudson Bay been have considered to be equivalent to one another.

The Nastapoka-Animikie series, forming the third major division of the pre-Cambrian in Laurentia, is of great importance, marking as it does one of the most widespread periods of submergence and depression in pre-Cambrian times, involving almost the whole continent of Laurentia. No division of the pre-Cambrian in Laurentia is exposed over such a great area of country. The positive movement which raised these rocks out of the sea was chiefly epeirogenic in character, for over the greater part of this area they still lie nearly flat. That the close of this time was, like those which preceded it, marked by an epoch of diastrophism, is shown by the widespread development of faults, accompanied in places by overthrusting. These are the superficial expression of the movements of deepseated intrusions, representing the last period of pre-Cambrian orogenic action. These post-Animikie granitic intrusions are to be seen on the east coast of Hudson Bay where, while the Nastapoka series in most places lies unconformably on the ancient Laurentian and the associated gneisses and schists, yet at some points it is cut by granitic intrusions.

This epoch of mild diastrophism brought to a close the third great period in the pre-Cambrian history of Laurentia.

The Nastapoka series seems to be the youngest division of the pre-Cambrian now found in the region east of Hudson Bay, but west of this inland sea, in a district bordering the southern shores of Lake Athabasca and stretching over an area of perhaps 24,000 square miles, is a great development of coarse sandstone in thick beds which along the shores of the lake aggregate at least four hundred feet in thickness. These, the Athabasca sandstones, lie in nearly horizontal positions, at times with a conglomerate layer at their base composed of fragments of the Laurentian granites and gneisses on which they rest with a strong unconformity. The Athabasca sandstones, or a very similar series, are exposed for a long distance up the valley which is continued seaward by Chesterfield Inlet, situated far north on the western shores of Hudson Bay. Between Lake Athabasca and the above locality, and in places associated with similar sandstones, are extensive areas underlain by basic and acid volcanics, porphyrites, and porphyries. These sandstones and volcanic rocks are, by the Canadian survey, classed provisionally as of pre-Cambrian age and it seems not improbable that they are later than the groups of rocks about Great Bear and Great Slave Lakes which have been correlated with the Nastapoka series. Thus it is possible that the Athabasca sandstones and associated volcanics are the northern representatives of the Keweenawan of Lake Superior, concerning whose pre-Cambrian age there is a similar doubt.

These sandstones are composed chiefly of quartz grains which it has been supposed have been largely derived from a series of quartzites known as the Marble Island quartzites and which on the western shores of Hudson Bay occur at intervals over a stretch of about one hundred and twenty miles. These are associated with masses of dark schists, etc., lying in a disturbed condition. The presence of siliceous material in the widespread Athabasca series, so like that composing the quartzites, would seem to indicate that these latter were at one time also widely developed. What their equivalents elsewhere are, if they have any, is not yet known. They apparently are older than both the Athabasca and the Nastapoka series and may belong to some division corresponding to the earlier Huronian.

The rocks of the Athabasca-Keweenawan series are unaltered and lie practically flat. They have not been affected by orogenic disturbances or deep-seated plutonic intrusions. The uplift which raised them from the waters of the ocean was epeirogenic in character. Since the close of the pre-Cambrian, the continent of Laurentia, while preserving its character as a positive element, has undergone many oscillations, but orogenic or mountain-making forces have never manifested themselves, and the successive epeirogenic uplifts have resulted in and to a certain extent been compensated by the deep and long-continued erosion to which the continent has been subjected throughout the greater part of post-Proterozoic time.

Using therefore the epochs of diastrophism, which mark the successive stages in the pre-Cambrian development of the continent, as a basis of correlation, provisionally grouping the Athabasca Sandstones with the Nastapoka series, it would appear that we have three major periods in the pre-Cambrian history of Laurentia separated by two critical epochs of diastrophism, with possibly a fourth period represented by the Laurentian rocks at the base of the series. That is to say we have three major periods in the pre-Cambrian succession separated by epochs of diastrophism, which diastrophism at each epoch exhausted itself for the time. These are as follows:

| | |
|---|---|
| Neo-Proterozoic | Keweenawan-Athabasca |
| | Upper Huronian or Animikie-Nastapoka |
| Meso-Proterozoic | Middle Huronian |
| | Lower Huronian |
| Eo-Proterozoic | Keewatin<br>(Intrusive contact)<br>Laurentian (embracing the original crust, if any remains) |

The lines drawn between the several subdivisions indicate unconformities, the heavier lines indicating the major breaks referred to in the text.

If we attempt to make a comparative study of the earlier continental evolution of North America and that of Asia, we note at the outset that the Siberian nucleus is a portion of that northern Polar region which comprises also Russia, Greenland, and Laurentia, against which stress has been continuously exerted by the denser masses of the more southern latitudes. As has been emphasized by Suess, the Siberian nucleus has been undisturbed since a pre-Cambrian date, and the same is essentially true of Laurentia also. We find that in Asia there were in geological time great mediterranea which, after they had been made the basins for the accumulation of great thicknesses of sediment, were successively closed by great thrusts from the south which folded up the sediments into mountain ranges and then converted these into dry land. In Europe the Alpine region was a marine strait in Cretaceous time, which was subsequently converted in this way into a mountain range.

In the North American continent, of which Laurentia forms a part, there seems to have been a somewhat similar sequence in continental development. Thus the Appalachian Mountains and the Cordilleran range of British Columbia represent ancient marine valleys or straits whose sediments are now folded into series of mountain ranges. The thrusts which closed up these mediterranea and developed mountain ranges from them, were exerted in a northeasterly direction against the southwestern part of the continent, and in a northwesterly direction against the southeastern border of the continent, so that the folds are parallel to the margin of the present continent of Laurentia. If we inquire whether similar long, narrow, belt-like mediterranea existed in Laurentia in pre-Cambrian times, the answer seems to be in the negative. The surface of the continent seems rather to have had upon it at intervals throughout geological time a succession of large, irregular-shaped bodies of water, somewhat resembling the present Hudson's Bay, in which, however, great thicknesses of sediment were accumulated.

The sediments deposited in these bodies of water in Keewatin, Grenville, and the Earlier Huronian times, were folded up into mountain ranges crossing the southern portion of the protaxis in a northeasterly and southwesterly direction, coinciding with the course of the Appalachian folding.

The intense diastrophism which brought to a close the Eo-Proterozoic and again the Meso-Proterozoic time was exerted apparently as far north as the middle of Labrador and the southern portion of Hudson's Bay.

In the later pre-Cambrian mediterranea the Nastapoka-Animikie series and the Athabasca-Keweenawan series were deposited. The almost entire absence of orogenic movement at the close of this time, combined with the great extent and comparatively unaltered character of the rocks, makes the break at the base of the Nastapoka-Animikie series probably the most pronounced in the whole pre-Cambrian succession in Laurentia. Thousands of square miles of practically flat-lying sediments overlie remnants of a highly folded and metamorphosed antecedent series.

We thus have two major breaks in the pre-Cambrian succession, each marked by an epoch of diastrophism which exhausted itself for the time.

An identical series of two major breaks in the Proterozoic succession, marked by epochs of pronounced diastrophism which in each case exhausted itself, is found in the Asiatic portion of the nucleus.

The succession here is as follows:[1]

| | | |
|---|---|---|
| Neo-Proterozoic | Tung-yu limestone | Slates, limestones and quartzite. |
| (Hu-t'o system) | T'ou-t'sun slates | |
| Meso-Proterozoic | Si-t'ai series | Chiefly chlorite schist; quartzite conglomerate at the base. |
| (Wu-t'ai system) | Nan-t'ai series | Siliceous marble, jasper, quartzite, and schist. |
| | Shi-toui series | Mica schists, gneiss, magnetite quartize, and basal feldspathic quartzite. |
| Eo-Proterozoic | T'ai-shan complex | Basal complex of varied gneisses and younger intrusions. |

The lowest of these series, the T'ai-shan, resembles the Keewatin penetrated by Laurentian intrusions, being

> a metamorphic complex, the constituents of which are largely igneous, though perhaps in part sedimentary in origin.[2]

This was brought to a close by a period of intense diastrophism. Suceeding this:

> We distinguish with great certainty a great thickness of very early Proterozoic sediments—the Wu-t'ai—which were intensely deformed and metamorphosed during a mid-Proterozoic epoch of orogeny, owing to pressure exerted by the outlying negative elements, and a later Proterozoic series—the Hu-t'o—which represents shore conditions and which was moderately deformed by pressure exerted by the same cause at the close of the Proterozoic.

Applying therefore this criterion of diastrophic epochs to the correlation of the Proterozoic succession of these widely separated portions of the great northern nucleus, we obtain an identical result in both cases—the diastrophic movements seem to have affected the nucleus as a whole.

It would seem that these diastrophic epochs designate certain of the unconformities in the succession both in the Siberian portion of the nucleus and in Laurentia, as major, dominant, and of special importance, and others as subordinate and of minor importance. We thus have indicated a division of the Proterozoic into Eo-, Meso- and Neo-Proterozoic. On this basis of correlation the T'ai-shan corresponds to the Keewatin-Laurentian complex; the Mu-t'ai to the Lower and Middle Huronian, and the Hu-t'o to the Animikie-Nastapoka series.

[1] *Research in China*, Vol. II, p. 4.

[2] *Ibid.*, Vol. I, Part I, p. 19.

These major breaks would seem to be as well marked and as important as those which characterize the separation of the Eo-Paleozoic and the Neo-Paleozoic in eastern America, or perhaps as that which brings to a close the Paleozoic succession in Europe.

If, as our knowledge of the pre-Cambrian becomes more complete, the correlation of these rocks over great areas by a time relation to diastrophic epochs proves to be generally applicable, we have a basis of correlation of great value and importance. This will constitute a great advance as compared with our present methods, which afford no adequate means of determining the relative values of unconformities and thus the successions in the most distant parts of the world are now being matched with each other and an unwarranted satisfaction is manifested if the number of unconformities in the pre-Cambrian succession in different continents is approximately identical, and a sure and certain hope that all will prove to be satisfactory is expressed if there is no agreement.

All that we really know at present is that

> there are great sequences of pre-Cambrian sedimentary formations, separated by many gaps from each other, which give one picture, growing less distinct in outline the farther back one goes, of the remotest periods of geological history, or, in other words, of periods of the earth's pre-historic age which is, according to the author's opinion, probably of greater length than all subsequent geological time.[1]

It is believed, however, that through the recognition of these diastrophic epochs, the dominant outlines of these pictures may perhaps be more clearly brought out and the relative values of the different parts thrown into relief in the case of each individual positive element, and that these epochs which have marked the successive stages of advance in Paleozoic and Mesozoic times, may thus be employed with advantage in deciphering the history of the pre-Cambrian as well.

## DISCUSSION

### CHARLES R. VAN HISE

It is with pleasure that I discuss briefly Dr. Adams' paper, since, allowing for differences of terminology, I find him in nearly complete accord with the

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[1] J. J. Sederholm, *Explanatory Notes to Accompany a Geological Sketch Map of Fenno-Scandinavia,* Helsingfors, 1908, p. 31.

United States geologists in reference to the succession and relation of the pre-Cambrian series of Canada. So far as there are differences they will appear below.

The elucidation of the pre-Cambrian succession for the Lake Superior region, which term as here used includes the great tract extending from the Lake of the Woods to north of Lake Huron and south to the Paleozoic rocks, has been the work of many men extending through many years. In 1892, when *Bulletin 86* of the United States Geological Survey, on the Archean and Algonkian appeared, the Lake Superior succession, as now recognized, had been fully worked out,[1] with the exception that what was then called the Lower Huronian has since been found to comprise two series; also the series now called Keewatin was called Mareniscan, but was properly defined. Some years after the publication of this bulletin, Mr. A. E. Seaman discovered the unconformity mentioned in the lower Huronian of the Marquette district. As soon as this discovery was made it was appreciated that the two divisions of the Huronian in the original Huronian area worked out by Pumpelly, Leith, and myself, correspond with the two divisions in the Marquette district. The classification of the pre-Cambrian as thus developed was fully accepted by the International Geological Committee in 1904, and the table giving the succession was published by Leith in 1904, and by the committee in 1905, as follows:[2]

CAMBRIAN
Upper sandstones, etc., of Lake Superior
Unconformity
PRE-CAMBRIAN
Keweenawan (Nipigon)
Unconformity
Huronian { Upper (Animikie)
Unconformity
Middle
Unconformity
Lower }
Unconformity
Keewatin
Eruptive contact
Laurentian

This succession is repeated by Dr. Adams in his communication, except that the unconformities are omitted, and it is extended to the entire Canadian pre-Cambrian region.

It is indeed gratifying to have completely accepted for the great Canadian pre-Cambrian area the succession which has been worked out for the Lake Superior region, but Dr. Adams implies that his classification rests upon a sounder basis than the same classification offered by others since "drawing evidence from the area as a whole rather than from a few restricted areas on its southern border." But unhappily for the contention of Dr. Adams, it is still true that the Lake Superior region is the only very extensive area in which the detailed geology has been worked out and the full succession given in the table has yet been found. Also when the succession was originally worked out all available information in reference to Canada as a whole was considered and it was suggested that within the regions about Hudson Bay and the Copper Mines Rivers, the equivalents of at least two divisions of the Huronian and of the Keweenawan appeared to be present.[1]

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[1] C. R. Van Hise, "Archean and Algonkian," *Bull. 86*, U. S. G. S., p. 195.

[2] *Journal of Geology*, Vol. XIII, p. 104.

As to the question of a floor for the Keewatin, according to our view, the Keewatin is simply the most ancient series which has been discovered to the present time. Naturally being the oldest series discovered, we have not yet found the rocks upon which it was laid down, and we make no assumption in this matter. Dr. Adams speaks of the Keewatin as a sedimentary series. If he means by this that it is a series laid down at the surface, this characterization is correct. However, we have frequently pointed out that this series is essentially composed of igneous rocks, including both lavas and fragmentals, and is only very subordinately of ordinary sediments.

As to the position of the Grenville series, I hold my opinion in reserve. Miller and Knight have shown that in the Hastings district where the series which Adams places in the Grenville is most extensively developed, there is an unconformity in the sediments. It is their belief that the greater part of the Hastings sediments, including the great limestone of Adams, belongs above this unconformity, below which is the Keewatin. If they are correct in this view, the larger part of the Hastings series included in Adams' Grenville belongs not with the Keewatin but with the Lower or Middle Huronian.

Dr. Adams says in reference to correlation by diastrophism: "This will constitute a great advance as compared with our present methods, which afford no adequate means of determining the relative values of unconformities, and thus the successions in the most distant parts of the world are now being matched with each other and an unwarranted satisfaction is manifested if the number of unconformities in the pre-Cambrian succession in different continents is approximately identical, and a sure and certain hope that all will prove to be satisfactory is expressed if there is no agreement."

In my address before the Geological Society of America a year ago, I introduced the table of pre-Cambrian series for China with their separated unconformities as given by Willis. I remarked that the Lake Superior Algonkian series in their number and their separating unconformities present a remarkable similarity to the Algonkian of China, but said it would "not be well to too strongly emphasize the close correlation suggested." Also I mentioned the "possibility that in the future we may be able to correlate the unconformable series of the Algonkian in provinces separated as far from one another as the Lake Superior region and Northern China."[2]

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[1] Charles R. Van Hise, *Bull. 86*, U. S. G. S., pp. 496–502, 1892; *16th Annual Report*, U. S. G. S., Part I, pp. 807–9, 1896.

[2] "The Problem of the pre-Cambrian," *Bull. Geol. Soc. of Am.*, Vol. XIX, p. 26.

Dr. Adams in his paper repeats the quotation from Willis and makes an identical suggestion as to correlation, but implies that this is done upon the basis of diastrophism. Evidently he thinks that there is an "unwarranted satisfaction" in the first case and not in the second.

Each unconformity between any two series of the Canadian region or of China means that between their depositions there has been an epoch of diastrophism and one of erosion. I should be interested to know how the extents and the magnitudes of pre-Cambrian diastrophisms are to be determined except by studying the extents and magnitudes of the unconformities, that is, the extent and amount of the foldings, metamorphisms, erosions, etc., which intervened between the various series. In the paper which I have just read I pointed out that some unconformities are local, some regional, and some probably intercontinental. Adams points out that diastrophism may be regional or intercontinental. Is the distinction between the two greater than difference in language? One we may suggest talks English, the other Esperanto. Evidently if satisfaction is unwarranted in one case it is unwarranted in the other.

I am obliged to dissent altogether from the reasoning in Dr. Adams' paper which makes discriminations as to the magnitudes of the various breaks, upon the basis of Willis's hypothesis of positive and negative continental elements, and upon assumptions as to the sources of the thrusts. Even if these theories be assumed to be correct we do not know that they apply to the North American pre-Cambrian region, for we know nothing of the extent and distribution of the various pre-Cambrian series which are hidden under later rocks. In the western United States where extensive areas of pre-Cambrian protrude through the later rocks, and also in the Mississippi Valley, where are isolated areas of pre-Cambrian, several pre-Cambrian series occur, some of which are probably the equivalent of the series found in the Lake Superior region. Evidently the various pre-Cambrian diastrophic movements cannot be assumed to be limited to the surface areas of pre-Cambrian.

The question of the major groupings of the pre-Cambrian series I shall not attempt to go into in detail, since to do this would result in leaving less emphatic the reality of the accord as to the pre-Cambrian succession which has now come about and which I trust has come to stay between the Canadian and United States geologists, through the acceptance for Canada of the succession mainly worked out in a great area along the southern border of the pre-Cambrian region.

However, I may recall that I fully discussed the major classification of the pre-Cambrian in my presidential address before the Geological Society a year ago, and gave reasons for the primary divisions of the pre-Cambrian into the Archean and Algonkian. In that address I gave objections to a zoic classification, similar to but not identical with that which Dr. Adams adheres to. His proposed major classification is eo-proterozoic, meso-proterozoic, and neo-proterozoic. These terms imply that the pre-Cambrian had three distinctive life periods, an *eo*, a *meso*, and a *neo*. This may be the case, but until fossils are found in the pre-Cambrian in sufficient abundance to justify a zoic classification, there can be no sufficient warrant for proposing that the major divisions of the pre-Cambrian be made upon a zoic basis.

## CLOSING DISCUSSION BY THE AUTHOR

The aim of the paper on "The Basis of Pre-Cambrian Correlation" was, as stated, to suggest a method by which it might be found possible to correlate the various subdivisions of the pre-Cambrian rocks over widely extended areas rather than to enter upon a discussion of the classification of the pre-Cambrian of North America.

With regard to this latter classification, however, it must be pointed out that the paper shows that in a general way the classification adopted by the International Committees (United States and Canada) on the "Correlation of the Pre-Cambrian Rocks of the Lake Superior Region" and on the "Pre-Cambrian Rocks of the Adirondack Mountains, the Original Laurentian Area of Canada and Eastern Ontario," probably forms a satisfactory basis upon which the classification of the whole expanse of the great pre-Cambrian development of the Laurentian protaxis can be founded. Professor Van Hise is mistaken in stating that in the paper under discussion the succession recognized by these committees was adopted but that the unconformities were omitted, for in the wall diagram used to illustrate the paper, and upon which the succession of the pre-Cambrian rocks in Laurentia and China was set forth, the unconformities were especially indicated, black lines being used to show those which were of minor importance while broad red lines appropriately emphasized the major breaks in the succession. The unconformities and their relative importance are also shown in the text of the paper. In fact, this is the crucial point of the paper so far as Laurentia is concerned.

Professor Van Hise has insisted, in a long series of papers, that in the pre-Cambrian succession of North America there is one break which in importance far transcends all others, namely, that at the close of the Keewatin. Professor Lawson, however, has insisted that in this succession the chief break lies at quite a different horizon, namely, at the base of the Animikie.

The International Committees, while recognizing the succession of the various elements of the pre-Cambrian, absolutely declined to commit themselves to any opinion as to the relative magnitude or importance of the several unconformities which they recognized.

A study of all the work—much of it recent—which has been done in the more northern portion of Canada indicates that Professor Lawson's break—the Eparchaean Interval as he terms it—is one of the greatest unconformities in the whole pre-Cambrian succession of Laurentia, and probably quite as important, if not more so, than the break at the close of the Keewatin, and that the pre-Cambrian rocks are represented, not by two great systems entirely distinct and separated from one another, but by three great systems.

In Professor Van Hise's presidential address he has referred to the succession of the pre-Cambrian rocks in Scotland, Finland, and China as determined by Geikie, Sederholm, and Bailey Willis, respectively, and notwithstanding the fact that in these successions from one to six unconformities exist, he has in each case selected one unconformity as of paramount importance, and correlating this with the break at the summit of the Keewatin in North America, has held that these various successions support a dual division of the pre-Cambrian rocks which he has maintained to be world-wide. He closes his address as follows: "I wish to express my firm belief that the dual division of the pre-Cambrian into two great groups of rocks [Archaean and Algonkian] seems now as firmly established as the division between any other two groups." I feel, as stated in the paper, that in this conclusion an "unwarranted satisfaction" is expressed.

To sum up, therefore, it seems that the division of the pre-Cambrian rocks of Laurentia into two great major divisions—Archaean and Algonkian—is not supported by the facts in our possession. The pre-Cambrian succession is apparently rather threefold, which three divisions may, for convenience, best be designated as Lower, Middle, and Upper (Eo- Meso- Neo-) Proterozoic, quite independent of any consideration of the presence or absence of life.